Near Earth Asteroid Observation Program

Subcommittee on Disaster Reduction

Lindley Johnson
Program Executive
Planetary Science Division
NASA HQ
4 April 2013
Is this a Current Day Threat?

Meteor Crater
Winslow, Arizona

Diameter – 1.2 km
Age – 50,000 yrs

Impactor size - ~50m
Energy released = ~10Mt
Confirmed Craters North America

http://www.unb.ca/passc/ImpactDatabase

Courtesy
University of New Brunswick, Canada
“U.S. early warning satellites detected a flash that indicated an energy release comparable to the Hiroshima burst. We see about 30 such bursts per year, but this one was one of the largest we have ever seen. The event was caused by the impact of a small asteroid, probably about 5-10 meters in diameter, on the earth's atmosphere.”

--Statement of Brigadier General Simon P. Worden, Deputy Director for Operations, United States Strategic Command before the House Science Committee Space and Aeronautics Subcommittee on Near-Earth Object Threat October 3, 2002
## A Low Probability but High Consequence Risk

### Estimated Impact Frequencies and Energies

<table>
<thead>
<tr>
<th>Type of Event</th>
<th>Diameter of Impact Object</th>
<th>Impact Energy (MT)</th>
<th>Average Impact Interval (years)</th>
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</thead>
<tbody>
<tr>
<td>High altitude break-up</td>
<td>&lt; 30 m</td>
<td>&lt;5</td>
<td>1 - 50</td>
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<tr>
<td>Tunguska-like event</td>
<td>&gt; 30 m</td>
<td>&gt;5</td>
<td>250 - 500</td>
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<tr>
<td>Regional event</td>
<td>&gt; 140 m</td>
<td>~150</td>
<td>5,000</td>
</tr>
<tr>
<td>Large sub-global event</td>
<td>&gt; 300 m</td>
<td>~2,000</td>
<td>25,000</td>
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<tr>
<td>Low global effect</td>
<td>&gt; 600 m</td>
<td>~30,000</td>
<td>70,000</td>
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<tr>
<td>Medium global effect</td>
<td>&gt; 1 km</td>
<td>&gt;100K</td>
<td>1 million</td>
</tr>
<tr>
<td>High global effect</td>
<td>&gt; 5 km</td>
<td>&gt;10M</td>
<td>6 million</td>
</tr>
<tr>
<td>Extinction-class Event</td>
<td>&gt; 10 km</td>
<td>&gt;100M</td>
<td>100 million</td>
</tr>
</tbody>
</table>
The TUNGUSKA EVENT

June 1908 – 104 years ago
And Now Chelyabinsk
What we know now

- Impact event occurred at 3:20:26 UTC (9:20 AM local time); Trajectory was ~east to west across Chelyabinsk, Russia (Southern Urals)
  - Observed from Tyumen, Ekaterinaburg, and Northern Kazakhstan
- Size ~17-20 meters
  - ~9,000 to 11,000 metric tons
  - Energy of this impact released 440 - 470 of kilotons equivalent TNT
  - Altitude of explosion at ~23 km
  - Velocity of impact 18 km/s ( > 40,200 mph)
  - Not related to 2012 DA$_{14}$ flyby [15 Feb 2013; that flyby was South to North]
- Largest reported fireball since Tunguska impact (on 30 Jun 1908)
- Much larger than 2008 TC$_3$ (which impacted in the Sudan) and ~1/10 the size of 2012 DA$_{14}$
- Reports that a few fragments have been recovered ~80 km west of Chelyabinsk (near a village called Satka)
- Blast wave damaged 4000+ structures (shallow graze ~15° entry; airburst and subsequent shockwaves from explosion)
- Report of 1200+ injured (no deaths), largely due to broken glass
This animated GIF image shows the meteor that entered the atmosphere above Chelyabinsk, Russia the morning of February 15, 2013 around 9:20 am local time, 0320Z. The GIF consists of 8 separate images starting at 0300Z and proceeding in 15 minute increments until 0445Z, at which time the vapor trail blends into the reflected light of the morning sun. The images show the horizon taken at the farthest extent of the EUMETSAT METEOSAT-10 satellite's high resolution visible channel, near latitude 55 north, longitude 61 west. Courtesy European Organisation for the Exploitation of Meteorological Satellites, and NOAA
Terminology

• “Near Earth Objects (NEOs)” - any small body (comet or asteroid) passing within 1.3 Astronomical Unit (AU) of the Sun
  – 1 AU is the distance from Earth to Sun = ~ 150 million kilometers (km)
  – NEOs are predicted to pass within ~ 45 million km of Earth’s orbit
  – Population of:
    • Near Earth Asteroids (NEAs)
    • Near Earth Comets (NECs) – also called Earth Approaching Comets (EACs)
      – 91 currently known

• “Potentially Hazardous Objects (PHOs)” – small body that has potential risk of impacting the Earth at some point in the future
  – NEOs passing within 0.05 AU of Earth’s orbit
    • ~ 8 million km = 20 times the distance to the Moon
  – Appears to be about 20% of all NEOs discovered

• NEOs accessible by human mission are a subset of PHOs
NEO Observation Program

US component to International Spaceguard Survey effort
Has provided 99% of new detections of NEOs since 1998

Began with NASA commitment to House Committee on Science in May, 1998 to find at least 90% of 1 km NEOs
– Averaged ~$4M/year Research funding 2002-2010
– Starting with FY2012, now has $20.5 M/year

Program Objective: Discover ≥ 90% of NEOs larger than 140 meters in size as soon as possible

NASA Authorization Act of 2005 provided additional direction:
“...plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90 percent completion of its near-Earth object catalogue within 15 years [by 2020].
NASA’s NEO Search Program
(Current Systems)

Minor Planet Center (MPC)
- IAU sanctioned
- Int’l observation database
- Initial orbit determination
www.cfa.harvard.edu/iau/mpc.html

NEO Program Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY
http://neo.jpl.nasa.gov/

End of Operations Feb 2011, Analysis Of Data Continues
Known Near Earth Asteroid Population

Known Near-Earth Asteroids
1980-Jan through 2012-Dec

- All NEAs
- Large NEAs

Start of NASA NEO Program

9726
3/24/13

861
3/24/13

15 January 2013
Alan B. Chamberlin (JPL)
Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)

Estimated Population

- 1 Billion
- 1 Million
- 1 Thousand
- 1 Hundred
- One

Assumes average albedo of 0.14

Absolute Magnitude, $H$

Diameter, Km

Brown et al. 2002
Constant power law
Discovered to 7/21/10
2010

Hiroshima

Assumes average albedo of 0.14
Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)

![Graph showing the population of NEAs by size, brightness, impact energy, and frequency. The graph plots the estimated population against absolute magnitude (H) and diameter (Km).](image)
Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)

Assumes average albedo of 0.14

- Estimated Population
- Impact Interval, years
- Impact Energy, MT
- Absolute Magnitude, H
- Diameter, Km

Brown et al. 2002
Constant power law
Discovered to 7/21/10
2010

Tunguska
K-T Impactor
Chicxulub Crater – KT Impactor

Demise of the Dinosaurs

Layer of Iridium across Earth’s surface
Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)

Estimated Population $N(<H)$

- Billion
- Million
- Thousand
- Hundred
- One

Assumes average albedo of 0.14

Protected by Earth's Atmosphere

Impact Interval, years

Impact Energy, MT

Absolute Magnitude, $H$

Diameter, Km

Brown et al. 2002

Constant power law

Discovered to 7/21/10

2010

Billion

Assumes average albedo of 0.14

Hiroshima

Protected by Earth's Atmosphere

K-T Impactor

Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)
Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)

Impact Energy, MT

Assumes average density and 20 km/sec impact velocity

Hiroshima

Impact Interval, years

Assumes average albedo of 0.14

Protected by Earth’s Atmosphere

Absolute Magnitude, $H$

Diameter, Km

Assessment of these data:

1. Population of NEAs by size, brightness, impact energy, and frequency is provided by Harris (2010).

2. The diagram illustrates the relationship between impact energy and magnitude, highlighting specific events like Hiroshima and Tunguska.

3. The impact interval and size distribution are also shown, with a focus on the relationship between absolute magnitude and impact energy.

4. The diagram assumes average density and a 20 km/sec impact velocity.

5. The albedo of 0.14 is assumed for Earth’s atmosphere.

6. The data points represent discovered NEAs up to 7/21/10.

7. The graph includes a constant power law and discovered NEAs to 7/21/10.

8. The K-T Impactor event is also highlighted in the diagram.
Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)

Assumes average density and 20 km/sec impact velocity

Assumes average albedo of 0.14
Known Near Earth Asteroid Population

Near-Earth Asteroids
Total Discovered per Size Bin

- Estimated Diameter (m)
  - ~30 (<<1%)
  - >100 (~10%)
  - >300 (~60%)
  - >1000 (~95%)

15 January 2013
Alan B. Chamberlin (JPL)
Spaceguard Survey Catalog Program
Current Spaceguard Survey Infrastructure and Process

Survey, Detect, & Report

Correlate, Determine Rough Orbit

Possible New PHO?

Routine Processing
Publish Results

Potential Impact?

Yes

Resolves Result Differences
Publish Results

Yes

MPC - PHO of interest
MPC - possible close approach
JPL - reports potential for impact
JPL - publishes probability of impact

No

Survey Systems
Minor Planet Center
JPL NEO Office*

Radar

Observe and Update Orbit

Impact Still Possible?

Yes

Precision Orbit and Follow Up Observations

No

Publish/Update Results

Alerts to NASA HQ

No

Iterate

Yes

MPC - PHO of interest
MPC - possible close approach
JPL - reports potential for impact
JPL - publishes probability of impact

* In parallel with NEODyS
Increased Radar Studies

Observations on the limited number of accessible objects, but next best thing to a flyby
– Detections/year from Goldstone and Arecibo doubled
– Required for timely precision orbit determination
– Characterization with sufficient signal strength
  • Shape, spin-state, surface structure
  • Satellites (and then derived mass)

Study of Shape, Size, Motion and Mass of 66391 (1999 KW4)

Shape, Size of 4179 Toutatis
# Close Approaching Asteroids in 2011

<table>
<thead>
<tr>
<th>Object</th>
<th>Closest Approach Date - Time</th>
<th>Min Dist. x Lunar</th>
<th>Relative Velocity (km/sec)</th>
<th>H Mag(v)</th>
<th>Size meters (est)</th>
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</table>
Pass of Asteroid 2005 YU55 Observed with Ground-based Radars

- 2005 YU55 passed by Earth the evening of 8 Nov, 2 at just less than 200,000 miles – within the Moon’s orbit
- Earth based planetary radars at Goldstone, CA and Arecibo, PR, were used to track and image the asteroid
- Planetary radar can be used to determine the size and shape of the asteroid, study its surface properties, and help predict any future encounters with the Earth
- The radar imaging shows the asteroid to be roughly spherical, about 1300 feet across, and rotating with a period of about 18 hours
- This event demonstrates how Near Earth Asteroids could be characterized by planetary radar for studies of potential human spaceflight destinations

This image of asteroid 2005 YU55 with about 12 foot resolution was obtained by Lance Benner at NASA’s Goldstone Radar on Nov. 7, 2011, about one day before closest approach, when the object was at 3.6 lunar distances, which is about 860,000 miles from Earth. NASA/JPL-Caltech

These two radar images were obtained by Patrick Taylor at the Arecibo Planetary Radar on Nov 12. The asteroid was about 2,000,000 miles away and the images show objects of about 25 feet in size. The image on right shows a radar bright feature, possibly a boulder on the asteroid's surface.

The Arecibo Observatory is operated by SRI International under a cooperative agreement with the National Science Foundation, in alliance with Ana G. Méndez-Universidad Metropolitana, and the Universities Space Research Association. The radar operations are funded by NASA.
Asteroid 2012 DA14 passed within about 3.5 Earth radii of the Earth's surface on February 15, 2013. Although its size is not well determined, this near-Earth asteroid is thought to be about 45 meters in diameter. Asteroid 2012 DA14 passed inside the Earth's geosynchronous orbit ring, located about 35,800 kilometers above the equator.
Images of 2012 DA14 spanning nearly 8 hours on Feb. 16. An elongated object is clearly revealed. Based on the changes the aspect ratio for this object is close to 2:1. Preliminary estimates the pole-on dimensions are roughly 40 x 20 meters.

A collage of the 2012 DA14 rotation obtained with a bistatic setup at Goldstone with DSS-14 transmitting and DSS-13 receiving: Feb 16, 00:46 – 08:31 UTC. The round-trip-time (RTT) to 2012 DSS14 changed from ~0.85 s to ~2 s during observations. Each frame is 320 sec of data integration. One full rotation is about 7 hours.
The Short Life of 2008 TC3

Discovered by
Catalina Sky Survey
Mt Lemmon Survey Telescope (1.5m) at
0640 on Oct 6, 2008.
~19 Mv
The Short Life of 2008 TC3

Initial MPC orbit determination finds object will impact Earth within 24 hrs. MPC alerts JPL NEO Program Office and HQ NASA
The Short Life of 2008 TC3

JPL SENTRY run predicts impact at 0245 on 7 Oct, 2008 over northern Sudan.

Community responds with 570 observations from 27 observers.
The Short Life of 2008 TC3

Impact trajectory of 2008 TC3 on 24 October 2008 at 00:00 UT

Predicted Impact Point

20°51'18.00"N 31°41'49.20"E
The Short Life of 2008 TC3
The Short Life of 2008 TC3

Impact Trajectory of 2008 TC3 on Earth

M. Elhassan, Noub
Recovery of 2008 TC3 Fragments

Discovery of 1st fragment by University of Khartoum students led by Dr. Muawia Shaddad with data supplied by NASA

Courtesy of Dr Petrus Jenniskens, SETI Institute

Enlarged image of TC3 fragment
What Could We Do About It?

Planetary Defense - Mitigating an Impact Event

• At the very least, “civil defense”
  • Days to weeks warning, evacuate area to be affected
• Technology exists to provide years to decades warning
  • And change the hazardous objects orbit
  • Need to find them as early as possible
• With Sufficient warning, 3 methods of Orbit Deflection
  1. Kinetic Impactor - instant push
  2. Gravity Tractor - slow pull
  3. Nuclear device - surface material blowoff
United States Government
Policy and Approach
Regarding Planetary Defense
• SEC. 803. REQUESTS FOR INFORMATION.
  • The Administrator shall issue requests for information on--
    • (1) a low-cost space mission with the purpose of rendezvousing with, attaching a tracking device, and characterizing the Apophis asteroid; and
    • (2) a medium-sized space mission with the purpose of detecting near-Earth objects equal to or greater than 140 meters in diameter.

• SEC. 804. ESTABLISHMENT OF POLICY WITH RESPECT TO THREATS POSED BY NEAR-EARTH OBJECTS.
  • Within 2 years after the date of enactment of this Act, the Director of the OSTP shall--
    • (1) develop a policy for notifying Federal agencies and relevant emergency response institutions of an impending near-Earth object threat, if near-term public safety is at risk; and
    • (2) recommend a Federal agency or agencies to be responsible for--
      • (A) protecting the United States from a near-Earth object that is expected to collide with Earth; and
      • (B) implementing a deflection campaign, in consultation with international bodies, should one be necessary.

• SEC. 805. PLANETARY RADAR CAPABILITY.
  • The Administrator shall maintain a planetary radar that is comparable to the capability provided through the Deep Space Network Goldstone facility of NASA.

• SEC. 806. ARECIBO OBSERVATORY.
  • Congress reiterates its support for the use of the Arecibo Observatory for NASA-funded near-Earth object-related activities. The Administrator, using funds authorized in section 101(a)(1)(B), shall ensure the availability of the Arecibo Observatory’s planetary radar to support these activities until the National Academies’ review of NASA’s approach for the survey and deflection of near-Earth objects, including a determination of the role of Arecibo, that was directed to be undertaken by the Fiscal Year 2008 Omnibus Appropriations Act, is completed.

• SEC. 807. INTERNATIONAL RESOURCES.
  • It is the sense of Congress that, since an estimated 25,000 asteroids of concern have yet to be discovered and monitored, the United States should seek to obtain commitments for cooperation from other nations with significant resources for contributing to a thorough and timely search for such objects and an identification of their characteristics.
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US Office of Science and Technology Policy (OSTP)
Letter to Congress dated 15 October, 2010*


The Director of OSTP will:

(1) develop a policy for notifying Federal agencies and relevant emergency response institutions of an impending near-Earth object threat, if near-term public safety is at risk; and

(2) recommend a Federal agency or agencies to be responsible for –

(A) protecting the United States from a near-Earth object that is expected to collide with Earth; and

(B) implementing a deflection campaign, in consultation with international bodies, should one be necessary

* http://www.whitehouse.gov/sites/default/files/microsites/ostp/ostp-letter-neo-senate.pdf
Background

• US National Space Policy, June 28, 2010*

NASA shall: “Pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-rich planetary objects.”

* http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

• US President’s FY2012 NASA Budget Request:

“The expanded Near-Earth Orbit Observation (NEOO) program [$20.4M] will improve and increase its efforts to detect Earth approaching asteroids and comets that may provide resources for our exploration of the inner solar system, or could become potential impact hazards to the Earth. It will also expand efforts to characterize their nature, both to better understand their composition and provide information for study of potential hazard mitigation techniques.”

• US President’s new plan for human space flight, announced April 15, 2010*, establishes the goal of conducting a human mission to an NEO by 2025

Within US Government:

• NASA will coordinate NEO detection and threat information from all organizations within the NEO observation community

• NASA has instituted communications procedures, including direction with regard to public release of information

• NASA notification procedures are set into motion only after the necessary observations, analyses, and characterization efforts have taken place to determine that a space object indeed represents a credible threat
  – Depends on level of risk and urgency, may unfold for years after detection
  – Will entail various combinations of:
    • Increased monitoring
    • Cross-checks of potentially hazardous trajectories as needed
    • Accelerated observations and orbit determination if potential hazard is near term
NEO Threat Notification

Upon notification from NASA:

Of impending NEO Threat to United States territory:

• The Federal Emergency Management Agency (FEMA) takes lead to notify appropriate Federal, state and local authorities and emergency response institutions utilizing existing resources and mechanisms
  – When time/location of affected areas known, activate National Warning System
  – Analogous to large re-entering space debris and/or hurricane warning procedures
  – Post-impact event, analogous to other disaster emergency and relief efforts

Of NEO Threat beyond United States territory:

• Recognizing vital role US efforts lead in NEO detection activities, US Department of State facilitates international notifications in effort to minimize loss of human life and property
  – Bilaterally through diplomatic channels to potentially affected countries
  – To member nations of multilateral forums – UN entities (OOSA, COPUOS), NATO, etc
  – Post-impact event, convey offers of disaster relief and technical assistance
Potential NEO Mitigation/Deflection

• Essential first step is continued enhancement of efforts to detect NEOs
  – Identify potential impact hazards early
  – Provide as much advanced warning of impact threat to enable more mitigation options

• Potential roles and responsibilities for mitigation options is in early stage of development and not yet ready for implementation
  – Wide range of possible scenarios and challenges involved
  – Significantly more analysis and simulation needed to understand feasibility and effectiveness of several approaches, and technical assessment of current technologies

• NASA to take lead to conduct foundational analysis and simulation, assessment of applicable technologies
  – Close coordination with DOD, FEMA, and other relevant departments and agencies
  – Possible emergency response exercises to be led by FEMA
  – Outreach to relevant private-sector stakeholders to leverage related work
  – Important to engage other nations and multilateral forums to explore opportunities for international cooperation, e.g. UNCOPUOS, European Union, ISECG
Future Plans for NASA NEO Program
Space Surveillance Telescope

- DARPA funded project
- Designed and built by MIT/LL
  - Same division as LINEAR
- Located Atom Peak, WSMR, NM
- 3.6 meter primary mirror
- First Light was Feb 2011
- Started 1 year of checkout
- Eventual operations by AFSPC
- First of 3 to 4 worldwide sites
- Serendipitous detection of NEOs in background mode to space surveillance
Near Term Impact Warning

Asteroid Terrestrial-impact Last Alert System – ATLAS*: A project to patrol the entire night sky every night in search of incoming asteroids.

A geographically dispersed network (> 4 sites) of small coupled telescopes observing “shallow but wide” to provide more complete sky coverage for warning of near-term impact threats.

*Courtesy University of Hawaii Institute for Astronomy
Large Synoptic Survey Telescope

- 6.4-m effective diameter
- 10 sq deg field of view
- ugrizy optical filters
- 18,000 square degrees ++
- 2x15s exposures + 2 more within 60 minutes
- Survey entire visible sky every 3-4 days in 2 filters for 10 years

Initial Operations 2019?
Space-based “NEOStar” Concept

WISE

Kepler

≈

“NEOStar”
NASA has signed a Space Act Agreement (SAA) to support B612 Project Sentinel

- Established NASA Technical Consulting Team (NTCT)
- Supported B612 Project Concept and Integration Review (PCIR)
- NTCT members will also support Sentinel Operations and Data Analysis (SODA) Working Group
- SAA Schedule/Milestones:
  - Sentinel contract start date: Sept. 2012
  - Preliminary Design Review: Sept. 2013
  - Critical Design Review: June 2014
  - Launch: June 2016
  - Initial on-orbit data delivery: NLT launch +6 mos